



Performance and Emissions Characteristics of A Diesel Engine Fuelled With Palm Olein Oil Biodiesel

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خصائص الأداء والانبعثات لمحرك ديزل يعمل بالديزل الحيوي بزيت أولين
النخيل

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Abstract

Increasing demand for petroleum diesel, long to increase in harmful air pollution. Excessive use of diesel fuel, present an opportunity to develop environmentally friendly and renewable fuels for current diesel engines that have not been upgraded. The effects of using biodiesel, generated from palm olein oil and derived through transesterification, along with biodiesel and diesel fuels blends in varying percentages, as a fuel in a TD202, a small air-cooled single-cylinder diesel engine. According to the results of the experiments, as the biodiesel percentage in the blend increased, compared to fossil diesel, thermal efficiency declined by 2.84% and specific fuel consumption increased by 0.0438 kg/kW-h for B100. Moreover, the result obtained from the emissions analysis reflects that the average carbon monoxide (CO) value decreased by 0.03 % vol., hydrocarbon (HC) value decreased by 6ppm, carbon dioxide (CO₂) emission increased by 1.4 % vol. for the given load, and nitrogen oxides (NO_x) increased by 262 ppm, indicating that the mixture was stable in comparison with fossil diesel.

الخلاصة

تزايد الطلب على الديزل البترولي ، مما يؤدي لفترة طويلة إلى زيادة تلوث الهواء الضار. يوفر الاستخدام المفرط لوقود الديزل فرصة لتطوير وقود صديق للبيئة ومتجدد لمحركات الديزل الحالية التي لم يتم تحديثها. تأثيرات استخدام وقود الديزل الحيوي ، المتولد من زيت أولين النخيل والمشتق من خلال الأسترة التبادلية ، جنباً إلى جنب مع وقود الديزل الحيوي ووقود الديزل الممزوج بنسب متفاوتة ، كوقود في TD202 ، وهو محرك ديزل صغير أحادي الأسطوانة مبرد بالهواء. وفقاً لنتائج التجارب ، حيث زادت نسبة وقود الديزل الحيوي في المزيج مقارنة بالديزل الأحفوري ، وانخفضت الكفاءة الحرارية بنسبة 2.84٪ وزاد استهلاك الوقود النوعي بمقدار 0.0438 كجم / كيلوواط-ساعة بالنسبة لـ B100. علاوة على ذلك ، تعكس النتيجة التي تم الحصول عليها من تحليل الانبعاثات أن متوسط قيمة أول أكسيد الكربون (CO) انخفض بنسبة 0.03٪ حجماً ، وانخفضت قيمة الهيدروكربون بمقدار 6 جزء في المليون ، وزادت انبعاثات ثاني أكسيد الكربون (CO₂) بنسبة 1.4٪ بالحجم. بالنسبة للحمل المحدد ، زادت أكاسيد النيتروجين (NO_x) بمقدار 262 جزء في المليون ، مما يشير إلى أن الخليط كان مستقرًا مقارنة بالديزل الأحفوري.

Key words: Biodiesel, Acid-Catalyzed Esterification, Transesterification, Engine exhaust emissions, Performance

الكلمات المفتاحية: وقود الديزل الحيوي ، الأسترة المحفزة بالأحماض ، الأسترة التحفيزية ، انبعاثات عادم المحرك ، الأداء



INTRODUCTION

Diesel engines are getting more popular every year as a result of their high efficiency, lower fuel consumption, and lower pollutants[1]. Every year, over 11,000 million tons of fuels are consumed[2]. Resources will be drained very quickly as a result of this consumption. As energy consumption increases, so too does the output's impact on the environment. The combustion and burning of such fuels is the primary source of pollution dangers to health and the environment[3]. Utilizing biodiesel in engines provides performance and economic advantages in terms of combustion process and carbon emissions when compared to non-renewable sources [4]. The Cussons 5 kW single-cylinder air-cooled engine with a Ricardo comet-type swirl combustion chamber has been studied. Because the greatest percentage of biodiesel was 20%, biodiesel's brake thermal efficiency is lower than diesel's. Biodiesel's brake specific fuel consumption was 10% greater than that of fossil diesel. Biodiesel produces 51 % less carbon monoxide than diesel fuel, despite having higher NO_x emissions. Biodiesel reduced HC emissions by 55% compared to fossil diesel. [5] the experiments were conducted on a four-stroke, single-cylinder, diesel engine that show BTEs were determined for several fuels at low, medium, and full load situations. It was noticed that B20 performed better than the other mixes. The amount of biodiesel in the blends increased the amount of specific fuel consumption. In comparison to diesel fuel, B100 had 14.6 % higher BSFCs. According to [6] study on a air-cooled, naturally aspirated, single-cylinder, four-stroke, directinjection four-stroke diesel engine with a fixed speed engine show when compared to diesel fuel, the brake thermal efficiency of the B100 mix was found to be lower when compared to diesel fuel, brake specific fuel consumption, higher fuel blends, biodiesel lowered CO, HC, and NO_x emissions while increasing NO_x. [7] used four-cylinder, four-stroke, turbocharged CI engine. The researchers noticed that BTE decreased as the percentage of biodiesel in the blend increased. Biodiesel has a greater BSFC than diesel fuel. With a higher biodiesel percentage, HC and CO emissions are reduced. When comparing biodiesel to diesel fuel, NO_x emissions were greater for biodiesel. [8] used diesel engine mounte YANMAR TF 120-M. Biodiesel has a greater BSFC, and a lower BTE than diesel fuel. When compared to diesel fuel, CO emissions are higher, NO_x levels are higher, and HC levels are lower. Only a few researchers have been looking into palm olein oil biodiesel production and its potential for usage in internal combustion engines. The study main goal is to look at the engine performance and exhaust emissions of diesel engines that run on biodiesel fuel.

EXPRIMENTAL WORK

Materials and Methods

6 mole of methanol and 1 mole of palm olein oil react to produce six moles of biodiesel and one mole of glycerol. Personal experience and research have led to the development of these concepts. Palm olein oil was given by Etihad Food Industries Co. LTD. Palm olein oil, sodium hydroxide, methanol, and sulfuric acid provided from a local lab. in Najaf Governorate. A total of 50 g used in each surgery. 100 % pure methanol used. Sodium hydroxide is also used. In the treatment process, a catalyst of 95 percent purity sulfuric acid was used. Other significant components are a magnetic stirrer (hot plate), thermometer, and separating funnel.

Acid-Catalyzed Esterification

The reaction time, molar ratio of methanol to oil, acid catalyst number, and temperature are all critical parameters in the esterification reaction. After pouring 50g of oil into the catalyst, sulfuric acid was administered, followed by methanol. Methanol has a 3:1 molar ratio with oil. The mixture was heated to



60°C and stirred for 60 minutes at 250 rpm using a magnetic stirrer. The concentration of H₂SO₄ was 0.25 %wt. The mixture was heated to 65 oC for 25 minutes after the reaction was completed to evaporate the methanol and discard of it. The amount of free fatty acids could decreased by roughly 5% as a result of these efforts.

Transesterification Process

11 g of methanol were mixed with 0.375 g of sodium hydroxide and stirred constantly for 10 minutes to generate sodium methoxide. 50 g palm olein oil, preheated to 60°C, poured over palm olein oil with sodium methoxide, and stirred constantly with a magnetic stirrer at 300 rpm for 2 hrs, in a molar ratio of methanol to palm olein oil of 6:1. When the reaction is finished, the mixture is allowed to layers into 2 phases, the biodiesel is upper layer and the glycerol bottom layer, for 8-24 hrs. A separating funnel can be used to separate two materials with differing densities. The biodiesel process is washed by pouring water at 70 °C to remove methanol and the catalyst after separation. Table 1 shows the properties of the prepared biodiesel.

Table 1. Physical and chemical characteristics of biodiesel

No.	Name of test	Property
1	Density @25 °C	0.8748 g/ml
2	Kinematic viscosity @40 °C	4.681 cSt
3	Flashpoint	181 °C
4	Cetane number	53
5	lower calorific heating	37 MJ/kg

Experimental Procedure

Experiments were carried out using diesel and biodiesel at three different engine speeds with varied engine loads (0, 25, 50, 75, and 100 %) (1000, 1500, and 2000 rpm) as shown in fig.1 and 2. Before the tests began, the engine was warmed up with diesel fuel. The engine was first loaded at no load, then steadily increased during the tests. The experimental measurements were taken in 10-minute intervals at each constant speed and torque to ensure precise results. The emissions were averaged throughout the same time intervals.

Table 2. Technical details of the test engine

Items	specification
Dimensions	Width 400 mm Height 450 mm Depth 350 mm
Net weight	35 kg
Fuel type	Diesel
Fuel tank	Caramel/light brown-painted steel with vent and filter cap
Absolute maximum power	3.5 kW (4.8 hp) at 3600 rev.min ⁻¹
Continuous rated power	3.1 kW at 3000 rev.min ⁻¹
Bore	69 mm
Stroke/crank radius	62 mm/31 mm
Connected rod length	104 mm
Engine capacity	232 cm ³
Compression ratio	22:1
Oil type	Multigrade SAE 5 W-40
Oil capacity	2.6 Litre

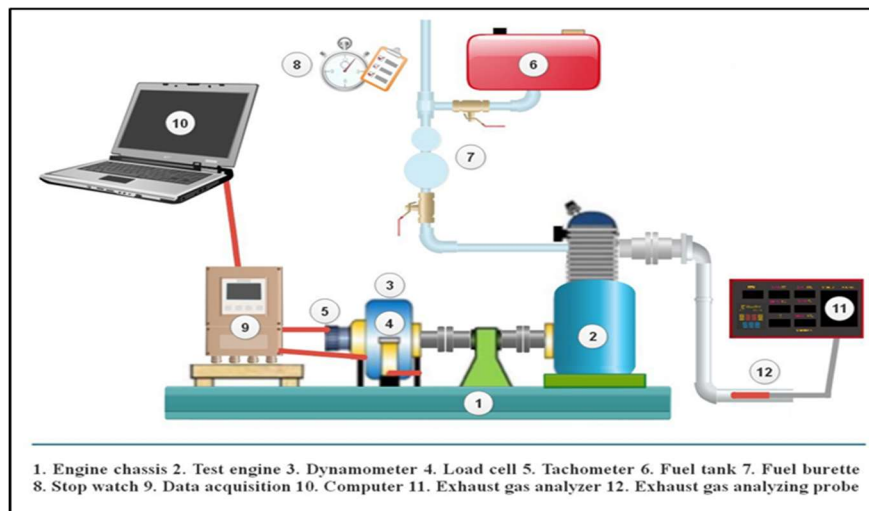


Fig. 1. Schematic diagram of the components of the experimental rig

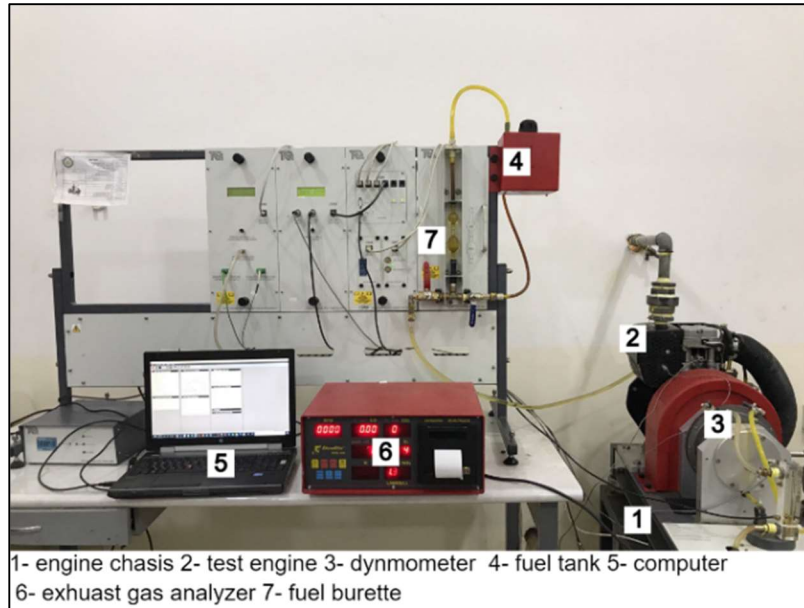


Fig. 2. The actual scheme of experiment

Mathematical Calculations

Brake power

Brake power calculated through equation. [9]

$$b.p. = \frac{2\pi NT}{60} \times 10^{-3} [kW] \quad \dots\dots(1)$$

Where

N: Engine speed (r.p.m), T: Torque (N.m), b.p. : Brake Power

Fuel Consumption

The fuel consumption is calculated by applying the equation below to get the time (t) it takes the engine to consume a given volume of fossil diesel. [10]

$$\dot{m}_f = \frac{\rho_f \times v \times 10^{-6}}{t} \times 3600 \left[\frac{kg}{hrs} \right] \quad \dots\dots(2)$$

Where:

$\dot{m}_f$: fuel consumption, ρ_f : fuel density (kg/m^3), t : fuel consumption duration (sec), v : volume of fuel = 8 mL

Brake Thermal Efficiency

The thermal efficiency can be calculated when the fuel consumption and power output have been calculated. [11]

$$\eta_t = \frac{b.p.}{\dot{m}_f \times Q_{HV}} \times 100 \quad \dots\dots(3)$$



Brake Specific Fuel Consumption

Another important metric produced within the same data was brake specific fuel consumption, which shows how effective the engine is at doing work with the fuel available. The formula below is used to calculate it. [11]

$$BSFC = \frac{\dot{m}_f}{b.p.} \quad \dots\dots(4)$$

Error Analyses

Instrument selection, calibration, condition, reading, environment, observation, and test preparation can all cause errors and uncertainties in the experiments. To confirm the experiments accuracy, uncertainty analysis is required.

Table. 3. List of instrument accuracy.

N o.	Instrument	numb er	Accuracy
1	Load cell	1	$\pm 0.025\%$ of the loc output
2	Optical sensor	1	± 100 RPM
3	Hydrometer	1	± 0.0001 g/ml
4	Graduated clynder	1	± 0.1 ml
5	Stop watch		± 0.01 sec
6	CO	1	± 0.01 %
7	CO ₂	1	± 0.1 %
8	NO _x	1	± 10 ppm
9	HC	1	± 10 ppm



Brake power uncertainty equation

$$\frac{\Delta b.p.}{b.p.} = \left(\left(\frac{\Delta N}{N} \right)^2 + \left(\frac{\Delta T}{T} \right)^2 \right)^{0.5}$$

$$\frac{\Delta b.p.}{b.p.} = 0.118 \text{ kW}$$

Fuel Consumption uncertainty equation

$$\frac{\Delta \dot{m}_f}{\dot{m}_f} = \left(\left(\frac{\Delta \rho_f}{\rho_f} \right)^2 + \left(\frac{\Delta V_f}{V_f} \right)^2 + \left(-\frac{\Delta t}{t} \right)^2 \right)^{0.5}$$

$$\frac{\Delta \dot{m}_f}{\dot{m}_f} = 0.0125 \text{ kg/hrs}$$

Brake thermal efficiency uncertainty equation

$$\frac{\Delta \eta_t}{\eta_t} = \left(\left(\frac{\Delta b.p.}{b.p.} \right)^2 + \left(-\frac{\Delta \dot{m}_f}{\dot{m}_f} \right)^2 + \left(-\frac{Q_{HV}}{Q_{HV}} \right)^2 \right)^{0.5}$$

$$\frac{\Delta \eta_t}{\eta_t} = 0.0354 \%$$

Brake specific fuel consumption uncertainty equation

$$\frac{\Delta BSFC}{BSFC} = \left(\left(\frac{\Delta \dot{m}_f}{\dot{m}_f} \right)^2 + \left(-\frac{\Delta b.p.}{b.p.} \right)^2 \right)^{0.5}$$

$$\frac{\Delta BSFC}{BSFC} = 0.032 \frac{\text{kg}}{\text{kWK}} - \text{hrs}$$

RESULTS AND DISCUSSION

Repeatability of Measurements

Every test has been conducted three times to guarantee that the experimental results are repeatable. In the analysis, the average of the repeated measurements was used. The test's repeatability is seen in fig. (3) and (4). For the same settings, differences between the tests have been documented. Instrumental faults, changes in the ambient circumstances, and human errors all contributed to this.

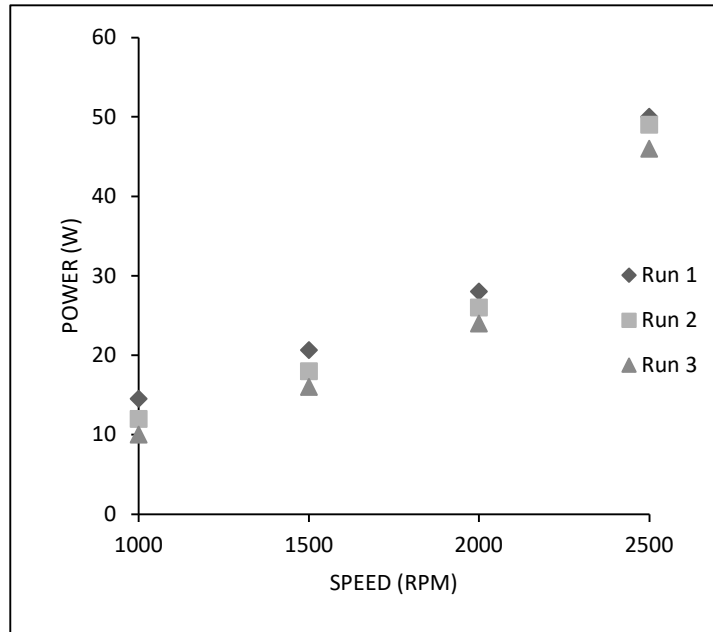


Fig.3. At zero load, power varies with engine speed.

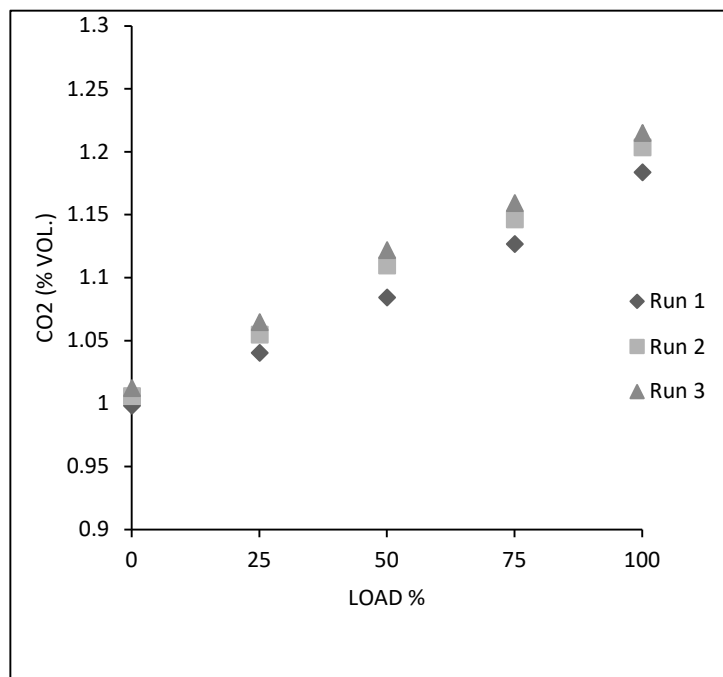


Fig.4. variation of CO2 and load at 2000 rpm

Engine Performance Characteristics

Brake Thermal Efficiency (BTHE)

cetane number, fuel quality, fuel optimization, fuel evaporation rate, combustion chamber geometry, fuel injection time, compression ratio, and pressure are all factors that affect diesel engine combustion. Burning can be enhanced by optimizing these characteristics, reducing the amount of fuel used and the rate of pollutants emitted by combustion. Combustion efficiency and cetane number are two important elements that influence diesel engine power and emissions. The BTE map for diesel - biodiesel fuel blends depending on engine load is shown in fig. 5. The thermal efficiency of B100 fuel blends at 1000 rpm fell by values of 1.55%, compared to fossil diesel, as shown in fig. 5. a. Figure. 5. b. The point is that when compared to fossil diesel fuels, the thermal efficiency of B100 fuel blends at 1500 rpm fell by 2.84%. The thermal efficiency of B100, fuel blends at 2000 rpm dropped by 2.11%, compared to diesel fuels, as shown in fig. 5. c. In fact, biodiesel has a lower calorific value than diesel, but it burns more efficiently due to its greater CN and oxygen content. Moreover, biodiesel is injected in a bigger bulk from a fuel pump with same volume capacity, and has a higher viscosity.

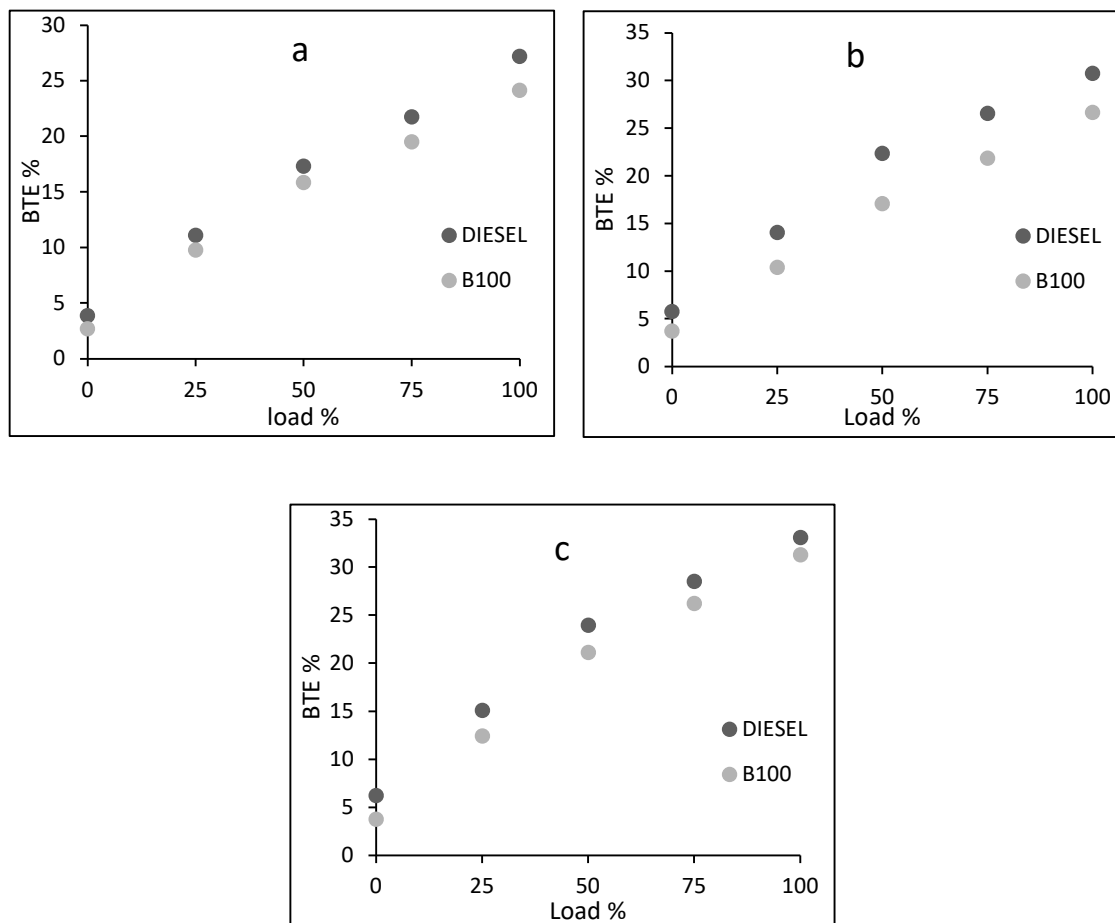


Fig. 5. BTE graphic according to engine load. a) at 1000 rpm, b) at 1500 rpm, c) at 2000 rpm
Brake Specific Fuel Consumption (BSFC)

The specific fuel consumption graph for diesel and biodiesel blends depending on engine load is shown in fig. 6. Figure 6 a. Depending on engine loads, specific fuel consumption rose by 0.194 kg/kW-h when

B100 fuel blends were compared to diesel fuel at 1000 rpm. Fig. 6. b. illustrates BSFC of B100, with fuel mixes increased by 0.115 kg/kW-h at 1500 rpm. Depending on engine loads, fig. 6. c. shows Brake Specific Fuel Consumption of B100, with fuel blends increasing by 0.13 kg/kW-h at 2000 rpm. The density, viscosity, and calorific heating value of the injected fuel have an impact on the BSFC factors. Due to the lower calorific value of biodiesel compared to fossil diesel, more fuel is pushed from the fuel pump to obtain the same output power as fossil diesel, resulting in higher BSFC.

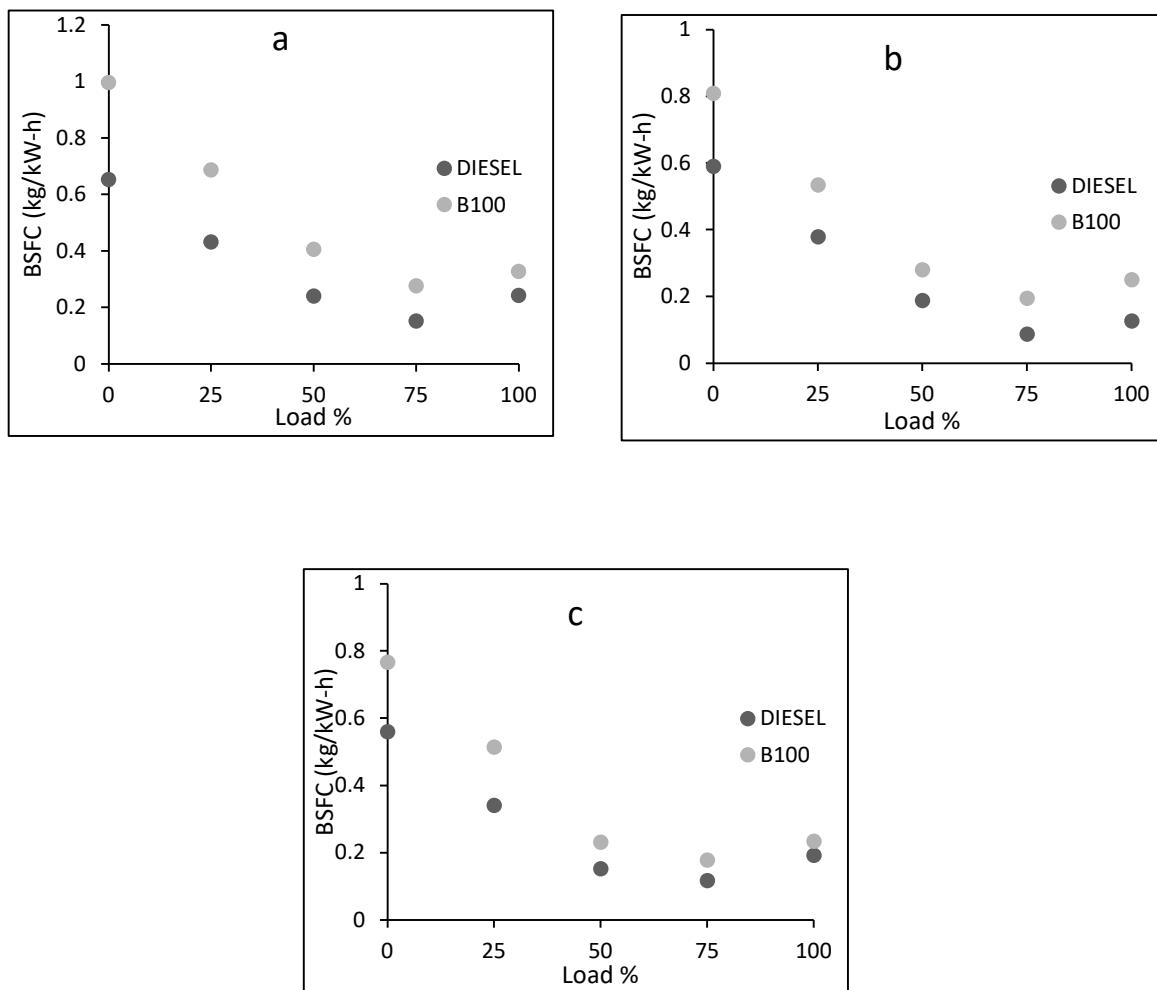


Fig. 6. BSFC graphic according to engine load. a) 1000 rpm, b) 1500 rpm, c) 2000 rpm

Engine exhaust emissions

Hydrocarbon (HC)

The graph depicts the changes in HC emissions from biodiesel and diesel depending on engine load. Figure 7 shows how HC emissions from biodiesel and diesel vary depending on engine load. Figure 7 a. B100 blends at 1000 rpm had produced lower HC emissions on average by 6ppm when compared to fossil fuels. Figure 7. b. shows that B100 blend at 1500 rpm has created reduced HC emissions on average by 27ppm when compared to fossil fuels. Figure 7. c shows that when compared to fossil fuels,

B100 blends at 2000 rpm yielded lower HC emissions of 21ppm on average. Biodiesel with a high Cetane Number may lower HC emissions. The oxygen concentration of biodiesel ensured adequate oxidizing in the rich air-fuel combination zones, which is why HC emissions were reduced when biodiesel and its blends were employed. The greater compression ratio of engines resulted in increased exhaust temperatures. As a result, unburned HC in the combustion chamber have been oxidized near the it of exhaust.

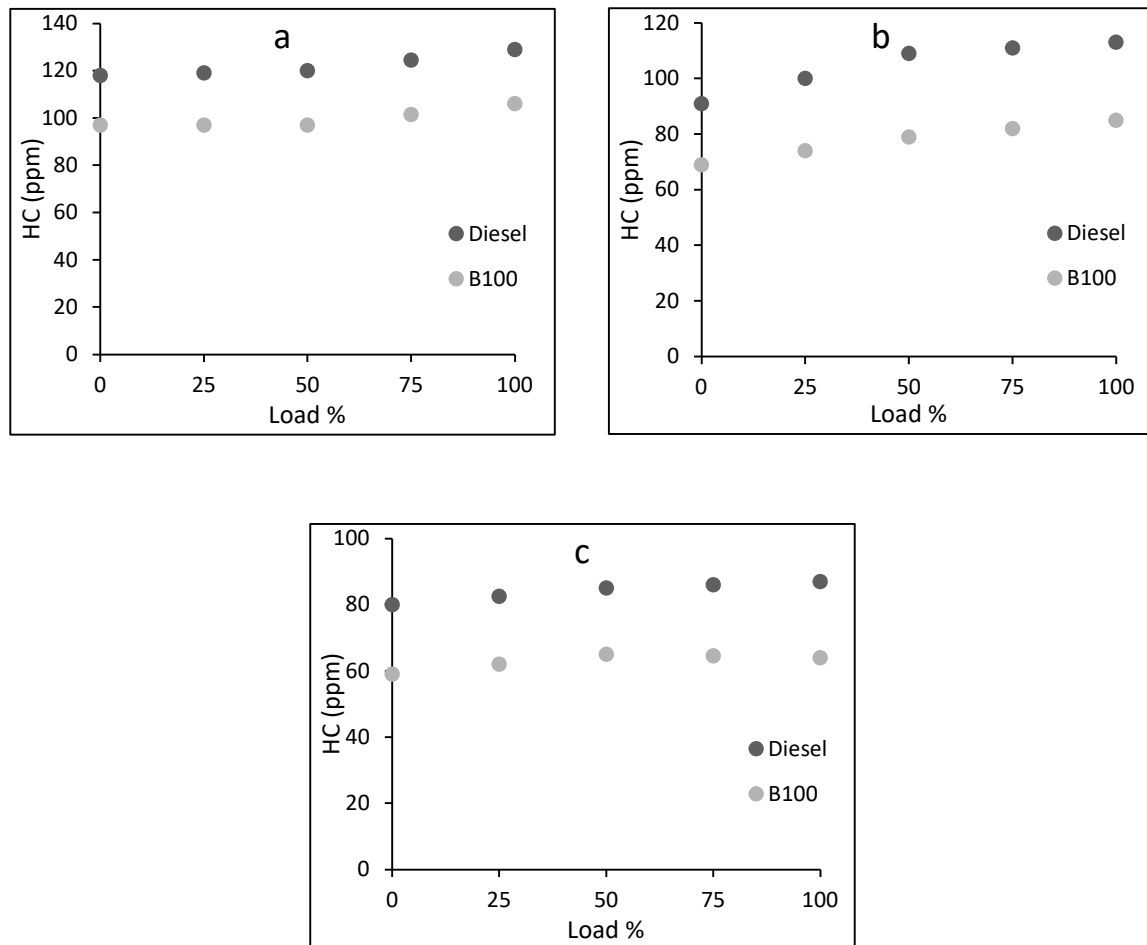


Fig. 7. Hydrocarbon (HC)graphic according to engine load a) at 1000 rpm, b) at 1500 rpm, c) at 2000 rpm

Nitrogen oxides (NOX)

Nitrogen oxides (NOx) are created when nitrogen in the air combines with oxygen at high temperatures in combustion engines. Figure 8. a. illustrates the NOx emissions of B100, which rose by an average of 332ppm at 1000 rpm, compared to diesel, depending on engine loads. In comparison to diesel, the NOx emissions of B100 fuels blends at 1500 rpm increased by an average of 312 ppm as compared to petroleum diesel, as shown in fig. 8. b. NOx emissions of B100 fuels blend at 2000 rpm rose by an average of 336 ppm (fig. 8. c). The faster combustion rate induced by sufficient oxidation in fuel-rich

zones due to biodiesel's oxygen levels is responsible for high specific fuel consumption within all biodiesel mixes compared to fossil diesel. As a result of higher NO_x, emissions induced by the higher chamber temperature.

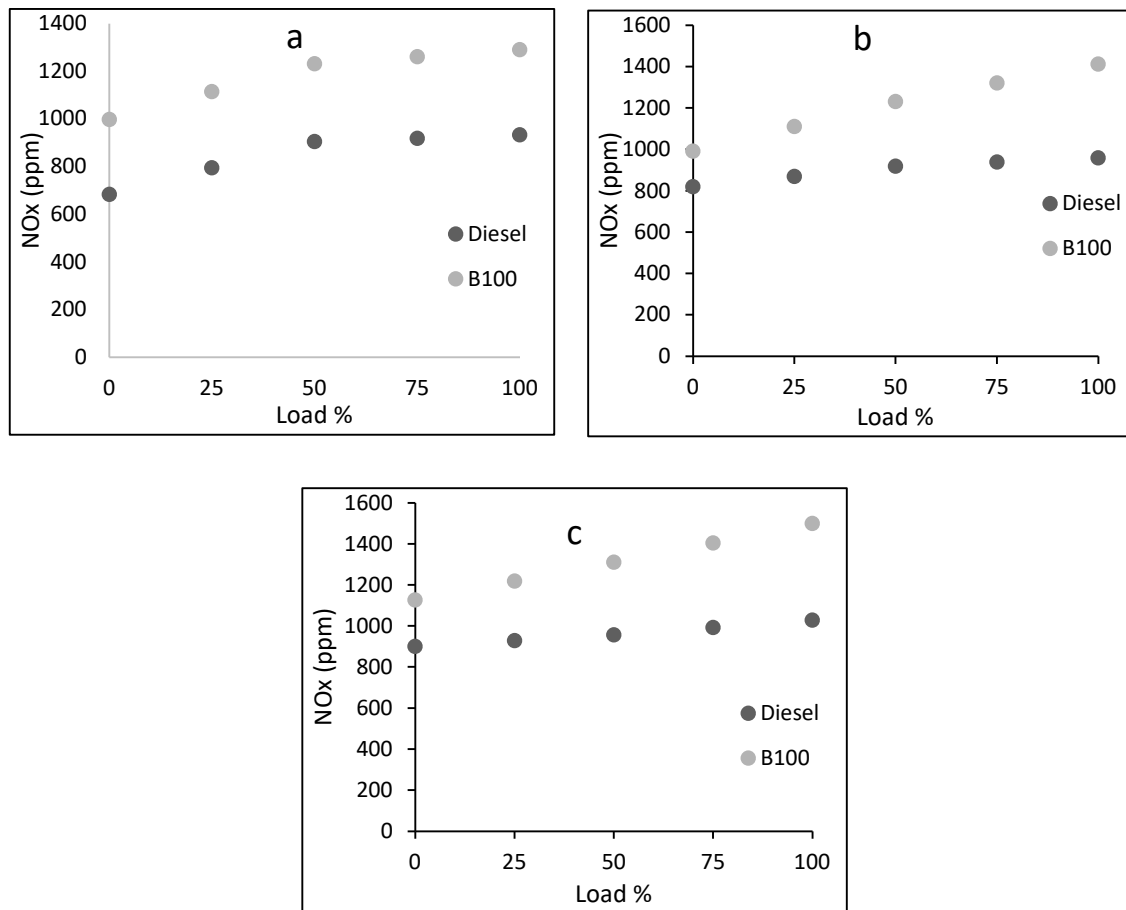


Fig. 8. Nitrogen oxides (NO_x)graphic according to engine load. a) at 1000 rpm, b) at 1500 rpm, c) at 2000 rpm

Carbon monoxide (CO)

Fig. 9 depicts the difference in CO emissions as a function of engine load. Fig. 9. a. shows CO emissions depending on the engine load, for B50, fuel blend at 1000 rpm. The CO emissions decreased by 0.072 %vol, compared to diesel. Fig. 9. b. shows that CO emissions depending on the engine load, for B100, fuel blend at 1500 rpm the CO emissions decreased by 0.068 %vol, compared to diesel. Fig. 9. c. shows that CO emissions depending on the engine load, for the B100 fuel blend at 2000 rpm and the CO emissions decreased by 0.066 %vol compared to diesel. Since diesel engines work with an enormous amount of air, CO emissions are typically low. Biodiesel has a higher cetane number than diesel fuel, as well as the oxygen content in it raised combustion and reduced CO emissions.

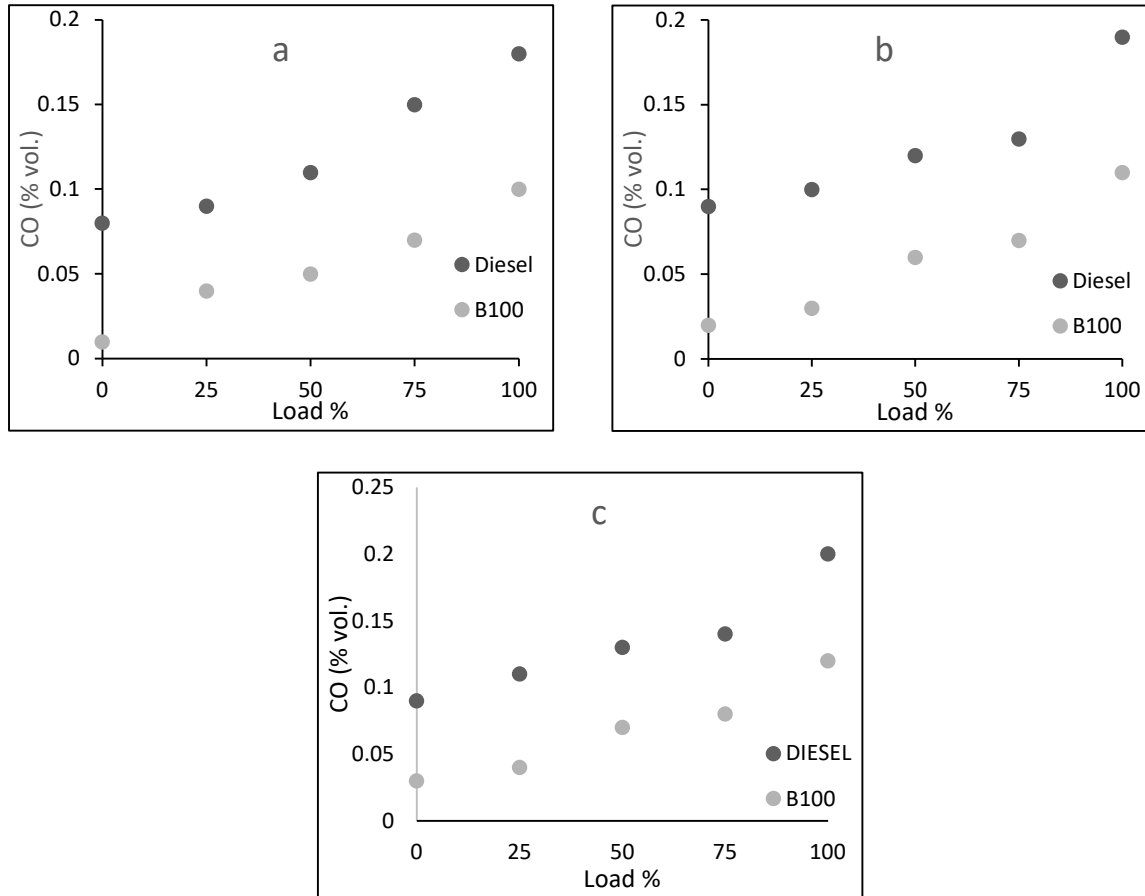


Fig.9. Carbon monoxide (CO) graphic according to engine load a) at 1000 rpm, b) at 1500 rpm, c) at 2000 rpm

Carbon dioxide (CO₂)

The CO₂ emission factor indicates total combustion. The change in carbon dioxide emissions as a function of engine load and fuel blend is shown in fig. 10. The CO₂ emissions of the B100 fuel mix at 1000 rpm rose by an average of 1.8 %vol. when compared to diesel fuel depending on the engine load, as shown in fig. 10. Figure 10. b. shows that the CO₂ emissions of a B100 fuel blend increased from an average of 1.4 %vol. at 1500 rpm, depending on the engine load, compared to diesel fuel. Fig. 10. c. reveals that at 2000 rpm, CO₂ emissions from the B100 fuel blend increased by 1.1 %vol. depending on the engine load, compared to diesel fuel

Because biodiesel contains more oxygen, CO₂ emissions rise potentially, leading to complete combustion. Plant life can use emissions of CO₂ from renewable energy sources to keep CO₂ concentration in the atmosphere steady.

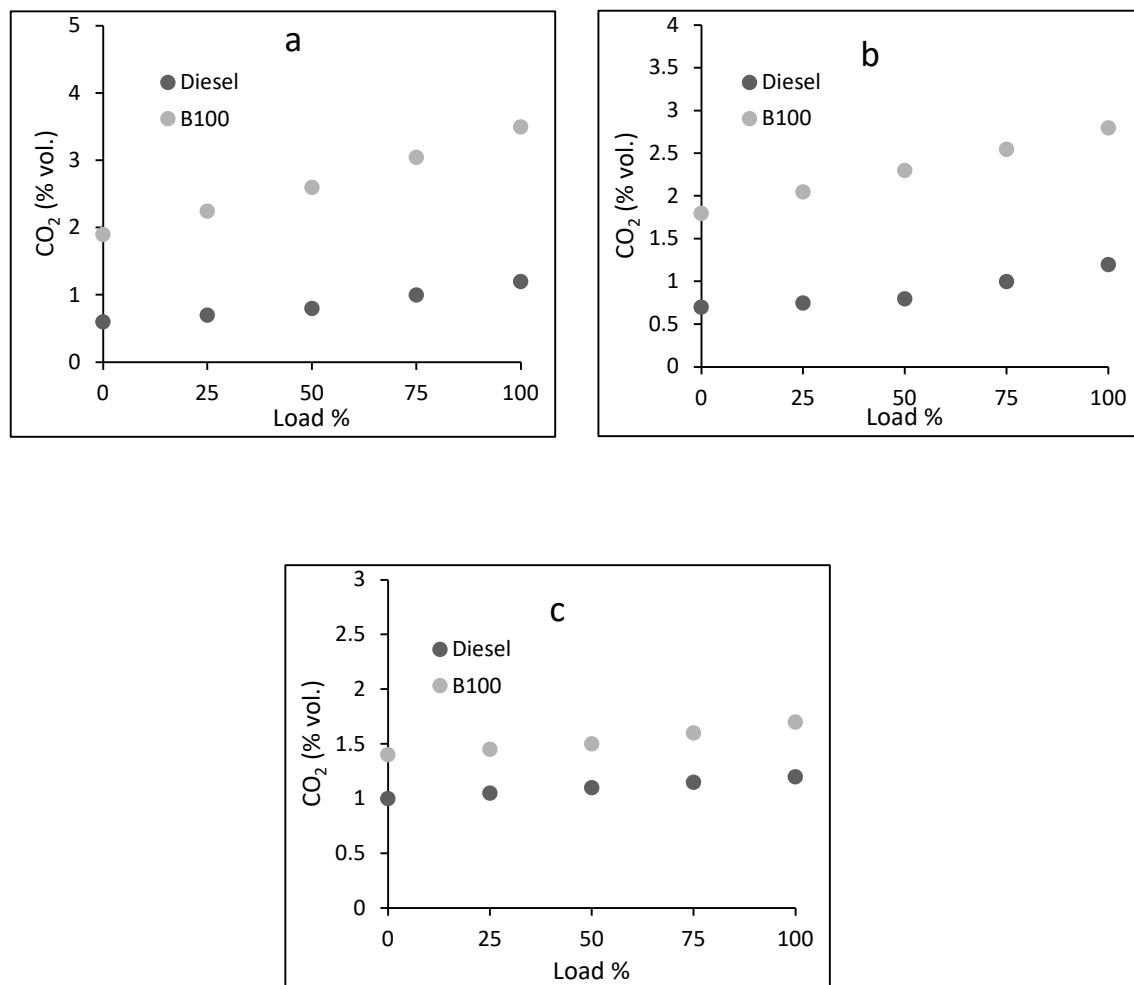


Fig. 9. Carbon dioxide (CO₂) graphic according to engine load. a) at 1000 rpm, b) at 1500 rpm, c) at 2000 rpm

CONCLUSION

Internal combustion engines get their energy from fossil fuels. According to papers, fossil fuel inventories are diminishing, and this depletion is fueling the search for alternative energy. Alternative fuels are being developed by researchers to minimize automotive exhaust pollutants and fuel usage. Biodiesel might be utilized in diesel engines without even any modifications or configurations, either in mixes with diesel fuel or in its pure form. There were no problems with the components of the engine during and after the investigation. Because of the lubricating properties of biodiesel, nothing hazardous was discovered in the combuston chamber. Due to the decreased calorific value of biodiesel relative to diesel, specific fuel consumption rose for all fuel blends. Both gasoline blends exhibited higher brake thermal efficiency than diesel. The study made use of biodiesel. The high CN of biodiesel allows combustion to be finished before the expansion time. Biodiesel reduced CO, and NO_x emissions while raising NO_x, and CO₂ levels.



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NOMENCLATURE

Symbol	Definition
BTE	Brake Thermal Efficiency
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
CN	Cetane Number
FFA	Free fatty acid
H ₂ SO ₄	Sulfuric acid
HC	Hydrocarbon
$\dot{m}_f$	fuel consumption
NaOH	sodium hydroxide
NO _x	Nitrogen oxides
η_v	Volumetric Efficiency
η_t	Brake thermal Efficiency

**Effects of material and geometry on composite
material behavior under compression**

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